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WASTEWATER TREATMENT PLANT CONTROL

Robert Smith

Environmental Protection Agency
Cincinnati, Ohio

July 1971

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by

Robert Smith

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Office of Research and Monitoring
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Cincinnati, Ohio 45226

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INTRODUCTION

The amount of instrumentation and automation installed in wastewater treatment plants should ultimately be determined on an economic basis. In any profit making industry such as the chemical process industry the degree of instrumentation and automation used can logically be based on the profit potential associated with plant automation. The product produced by a municipal wastewater treatment plant, however, is an effluent which can have a deleterious effect on the environment and the burden of less than optimum treatment must, therefore, be born by the public at large. The benefits of good wastewater treatment can still be evaluated, but since the effect of damage to the environment is difficult to quantify, the profitability analysis is not as straight forward. For example, for a specific plant and receiving stream situation it is possible to compute with reasonable accuracy the reduction in dissolved oxygen in the water downstream of the plant or the increase in coliform bacteria in the water as a result of the plant effluent. Similar analyses can be made for increased levels of nitrogen or phosphorus downstream of the plant. Placing a worth on the reduced level of dissolved oxygen or increases in levels of other contaminants, however, is extremely difficult to do to the satisfaction of everyone. A sounder approach is to assume that some level of effluent quality is required and examine the impact of new instrumentation and automation on either improving the effluent quality or on reducing the cost of treatment when the effluent quality is fixed. This approach will be taken in this paper.

We should recognize first that certain kinds of instrumentation and automatic control are essential to good operation and the payoff for installing such automation is well established. For example,

temperature control for the anaerobic digesters or level control in the wet well of the influent pumps. An influent meter at the head end of the plant is normally provided. Since no monetary penalty is associated with poor effluent quality, the degree of instrumentation and control in conventional plants has been traditionally low.

The goals of instrumentation and automation can be enumerated as follows:

- Improved effluent quality
- Reduced ultimate disposal cost
- Better adaption of time varying loads (concentration and volume flow)
- Reduced operating and maintenance cost
- Reduction in variability of effluent quality
- Better management surveillance
- Reduction in the size of equipment and structures for treatment
- Detect incipient problems and take corrective measures to avoid upsets
- Improve treatment reliability and avoid bypassing

It is axiomatic that before a control strategy can be applied, a measurement or measurements which define the condition of the process must be made. In addition to this, the equipment and structures associated with the process must be able to adapt in some way to bring the process back into control when the measurements indicate that some control action is needed. If these two primary requirements are not satisfied, control of the process is not possible.

A list of control schemes often considered for wastewater treatment plants are shown in Appendix I. The external and internal loads are disturbances which can drive the process out of control. To compensate,

the process must change in some way to achieve adequate treatment in spite of the disturbance. It is important to realize that for many disturbances such as storm overflows, excessive infiltration, dumps of oil, grease, industrial chemicals, or heavy metals no truly feasible control strategies exist at this time.

It should also be noted that the time constants associated with many of the treatment processes are long, measured in days and laboratory measurement of some variables is well within reason.

CONTROL LOOPS FOR CONVENTIONAL PLANTS

A diagram of a conventional plant is shown in Figure 1. Several principal control loops are shown on this diagram. Identification numbers shown on the diagram are references in the following discussion.

Raw sewage pumping into the plant is normally designed for on-off operation. A wet well is provided and a level control turns on the pumps sequentially to hold the level in the wet well at some set point. This results, especially in small plants, in a series of hydraulic steps being imposed on the plant. This kind of operation is known to have a deleterious effect on the performance of the plant. An alternative method is to provide variable speed pumps which will deliver a smooth hydraulic load to the plant. With perfect control the diurnal flow pattern at the interceptor discharge would be delivered to the plant without modification. The diurnal variation in flow tends to decrease as the size of the population served increases. This diurnal flow variation is also known to minimize the effectiveness of the plant. An ideal control scheme is to provide a flow equalization tank from which a constant volume stream is pumped into the plant. Experimental determination of this effect is not well established but computations with mathematical models have shown that the magnitude of the improvement possible with an equalization tank is about 20% based on the daily emission of BOD.

A liquid level sensor upstream of the bar screens can be used to actuate the cleaning mechanism when debris accumulates. This kind of control is primarily to save the time of the operator and is perhaps difficult to justify since a timing mechanism can be used to clean the screens at a fixed time interval.

CONTROL LOOPS FOR CONVENTIONAL PROCESSES

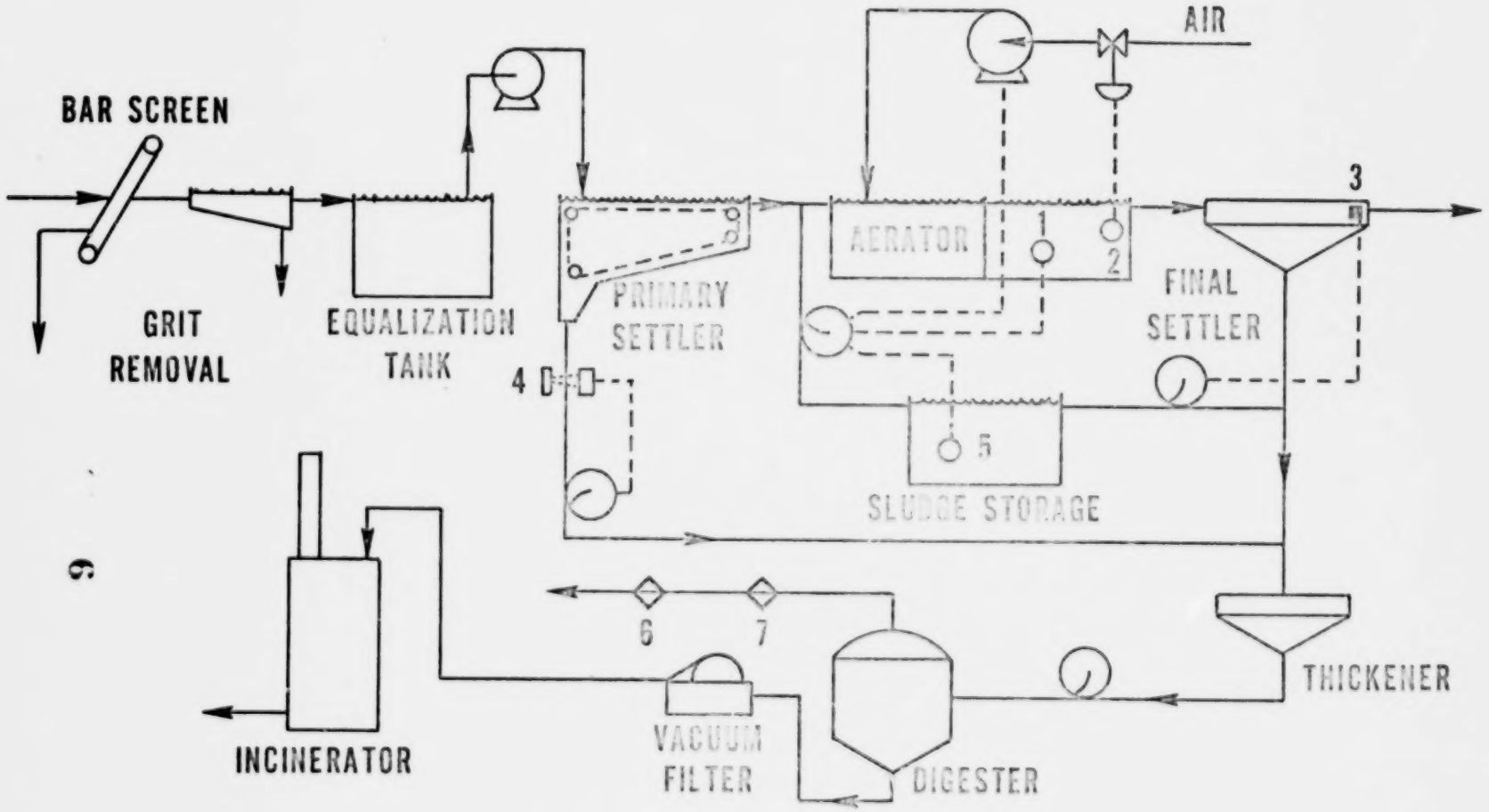


FIGURE 1

It has been suggested that liquid level sensors together with magnetic flow meters might be used to measure the velocity of flow in the grit chambers in order that the flow velocity can be held within the optimum range. The only control strategy available for velocity control is to distribute the flow between a greater number of grit chambers. The potential economic benefit of this scheme has never been evaluated.

Several possibilities exist for control of the primary settlers. The first is detection of failure in the skimming and scraping flights. If this mechanism fails, the result could be floating material being discharged to the secondary process or excess sludge accumulating on the floor of the settler. Shear pin monitors have been suggested for this application. In some cases the condition of the flights can be monitored visually by installing small battery operated lights on the moving flights. The economic feasibility of monitoring the scraping and skimming flights has never been evaluated.

Proper pumping of primary sludge from the underflow of the primary settler offers a good economic payoff in terms of better anaerobic digester performance. This can be accomplished by using a nuclear radiation density meter[4] in the sludge line. When the sludge density in the line exceeds some set point, the sludge pump is started automatically and the pumping cycle is stopped when the sludge density drops below some lower set point. The same kind of effect has been achieved by starting the pump at fixed intervals and stopping the pumps when the flow rate exceeds some set point. Since the performance of the anaerobic digester is controlled primarily by detention time, increasing the concentration of sludge in the feed stream increases the effective detention time in the digester.

The addition of chemicals such as alum, iron, or lime to the primary settler can be used to improve the effectiveness of the process. Chemical addition can be made proportional to flow or the chemical dose can be scheduled throughout the day to maximize the effectiveness of the chemicals since the required chemical dose varies with the suspended solids load on the process.

The activated sludge process offers more potentiality for control than most other conventional processes. The most obvious control loop is the dissolved oxygen loop which regulates the blowers or mechanical aerators to hold the dissolved oxygen level in the aerator at some set point. This can be done with centrifugal blowers by regulating a valve in the air line. With positive displacement blowers a bypass or a variable speed driving motor must be used. The sensor consists of one or more dissolved oxygen meters[2] installed in the aeration basin. The signal from the DO meter controls the supply of air to the process when diffused air is used. When mechanical aerators are used, the most common mode of control is to raise or lower the mechanical aerator in the water or to vary the water level by means of weirs. With this control scheme the savings in electrical power can be estimated. Variable speed drive motors can be used with mechanical aerators but the loss of efficiency at less than design speed minimizes the cost saving possible.

Another important control loop which can be used with the activated sludge process is control of the return sludge pump. The pump must be large enough to return all of the sludge even when the sludge compacts poorly. As the activated sludge accumulates in the final settler, the sludge density in the waste activated sludge

line increases and therefore to maximize the concentration of the waste activated sludges, the volume returned should not be greater than that necessary for good clarification. If the return pump is too small and is turned on too infrequently, the sludge will accumulate to a point where it begins to escape over the weirs of the final settler. A sludge blanket detector[3] is, therefore, an effective indicator to turn the return pump on and off. When the sludge blanket rises to a point where the product quality begins to deteriorate, the pump should be turned on. When the sludge blanket drops to a safe level, the pump should be turned off. This kind of control loop has the potential for maintaining good product quality while holding the concentration of waste activated sludge high.

The effectiveness of the activated sludge process is known to increase as the mixed liquor suspended solids (MLSS) concentration held in the aerator increases. If the MLSS is held too high, however, the final settler will be overloaded and the sludge will escape in the final effluent. The MLSS can be controlled by adjusting the rate of sludge wasting from the underflow of the final settler. Theoretically, the MLSS can be held within correct limits by closing the loop between the MLSS meter[1, 5] and the sludge wasting pump. In practice, it has been found that the time constant for this loop is very long and satisfactory control of MLSS can be achieved by manual adjustment of the sludge wasting rate. Laboratory measurement of MLSS might be adequate but an online meter to measure MLSS is available and use of this meter is probably the best solution.

A control scheme often proposed for the activated sludge process is to use a sludge storage tank to store activated sludge during periods of low load on the process which can then be reintroduced to the aerator during periods of high load. The economic advantage of this scheme over simply building a larger aerator has never been demonstrated.

Anaerobic digesters for reducing the dry solids concentration of sludge produced by conventional processes has long been recognized as an economically attractive process. Anaerobic digesters, however, can fail, or go sour, if the charging rate is not carefully controlled or if toxic materials are introduced with the raw sludge fed to the digester. Clearly, one important consideration is to have enough digester capacity distributed among several digesters so that overloads can be avoided. A practicable way of excluding toxic materials from the digesters is not known. Various kinds of measurements can be made in and around the digester to keep the digester in a healthy and productive condition.

For example, some plants measure gas production[6] as related to the charging rate. A drop in gas production signals trouble. Corrective action might be reduced charging rate, increased mixing, or even seeding from a nearby healthy digester. A popular measurement is carbon dioxide[7] concentration in the off gas. An increase in carbon dioxide signals trouble in the digester. Measurement of alkalinity, pH, and volatile acid concentration are often used to indicate the condition of the digester. A decrease in pH and an increase volatile acid concentration indicate that the digester is going sour. Again the corrective action is reduced charging rate,

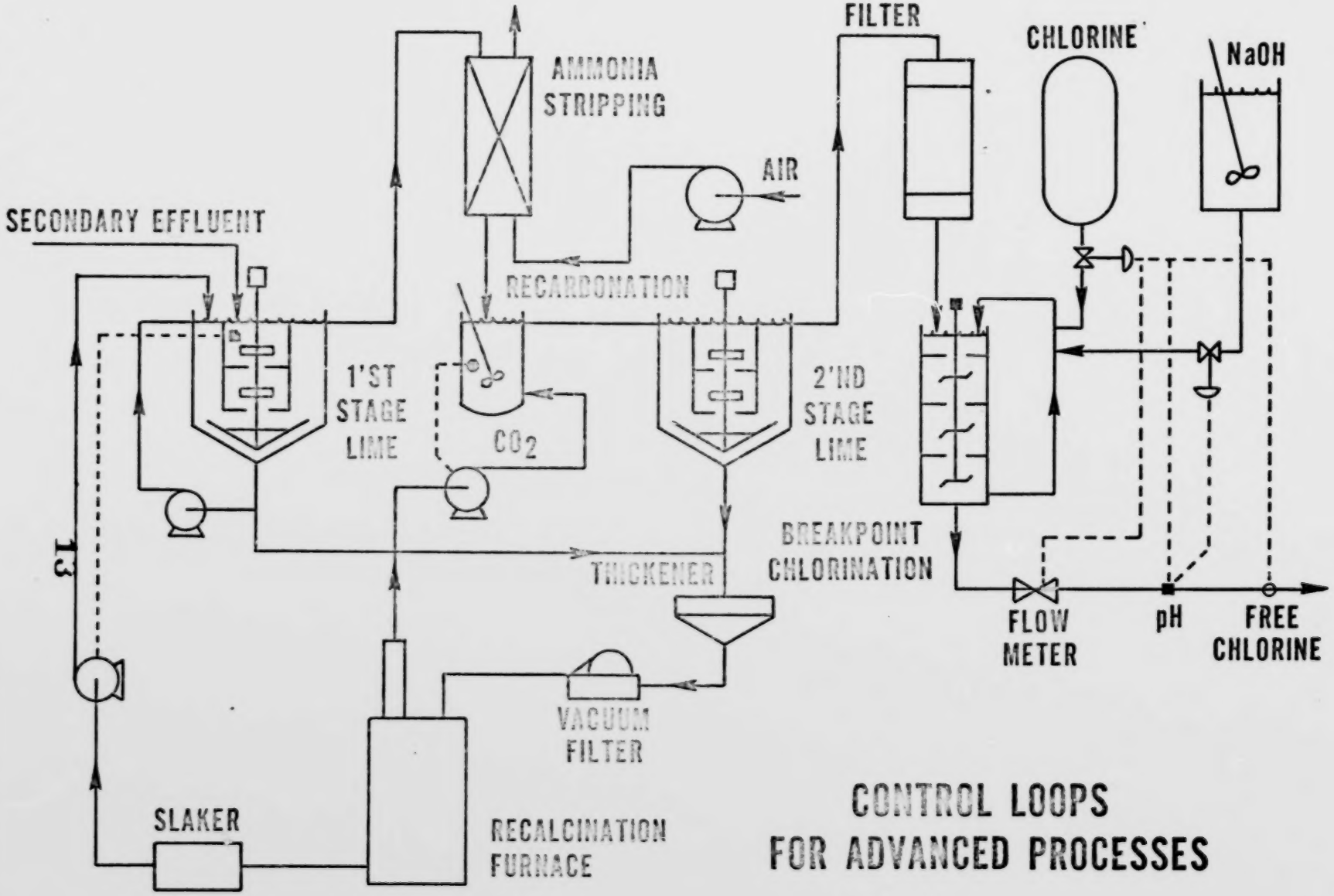
increased mixing, or seeding. Many plants, especially large plants, use some combination of these measurements with a control strategy tailored for the particular installation.

CONTROL LOOPS FOR ADVANCED WASTEWATER TREATMENT

For tertiary and independent physical-chemical treatment processes various kinds of control loops are essential for efficient and reliable operation. Most of these control loops involve feeding of chemicals or pH control.

For example, consider tertiary processes (Figure 2) which are used to improve the quality of water discharged from the conventional group of processes shown in Figure 1. One of the most common tertiary processes is addition of alum or iron to the aerator of the activated sludge process to remove phosphorus and improve settleability. The dose is normally two moles of Al per mole of P in the feed stream. In order to determine the alum dose the mass flow of the feed stream and the concentration of phosphorus in the feed stream must be measured. In addition to this, the removal of phosphorus accomplished by the addition of alum is most efficient when the pH of the water is in the range of 6.3 - 6.5. This pH can be maintained by using a pH meter as the sensor and controlling the addition of lime and carbon dioxide to hold the pH of the water within this range.

Nitrogen can be removed from wastewater by ammonia stripping or by biological nitrification followed by biological denitrification. In the denitrification dispersed growth reactor methanol must be supplied at a carefully controlled rate to act as a food for the microorganisms which reduce the nitrate ion to nitrogen gas. In both the nitrification and the denitrification steps the biological reaction tends to move the pH away from the optimum range. For best operation pH control loops should be installed on both the nitrification and denitrification processes.



CONTROL LOOPS FOR ADVANCED PROCESSES

FIGURE 2

An alternative method for removing ammonia nitrogen is breakpoint chlorination. This process must be carefully controlled to eliminate the formation of nuisance products such as nitrate and nitrogen trichloride. A control system which will reduce the ammonia nitrogen concentration to about $1\frac{1}{2}$ mg/l and also minimize the formation of nuisance products has been developed at the Joint EPA-D.C. Pilot Plant in Washington, D.C. This control system measures the concentration of ammonia nitrogen and the mass flow in the feed stream. The chlorine feed is then set at eight parts of chlorine per part of ammonia nitrogen. The addition of the chlorine tends to lower the pH and unless the pH is adjusted to the 7-8 range, nuisance products will be formed. The pH is adjusted by adding a solution of NaOH in response to a signal from a pH meter on the effluent stream. The concentration of free chlorine is measured in the effluent stream and the dose of chlorine is trimmed to hold the free chlorine residual to some set point. A patent on this control scheme has been applied for.

The lime clarification process is used to remove both phosphorus and suspended solids from secondary effluent. The two stage lime clarification process depicted in Figure 2 recycles lime sludge in the first reactor to keep the suspended solids in the 2000 - 4000 mg/l range. The waste calcium carbonate sludge is recalcined and returned to the first stage of the lime clarification process. The amount of lime fed to the process can be controlled by conductivity, pH, or alkalinity (Calgon Chemonitor). The pH of the reaction zone in the first reactor is held at 11.5. If ammonia stripping is used, the high pH water is then directed to the top of the ammonia stripping

tower. Following stripping the water is recarbonated using gaseous carbon dioxide to remove the excess calcium ions. The pH in the recarbonation reactor is held at about 10.3 by means of a control loop in which a pH meter controls the rate at which carbon dioxide is fed to the reactor. Additional precipitation occurs in the second stage of the lime clarification process and a multi-media filter is required to remove the inorganic haze which escapes over the weirs of the clarifier. When breakpoint chlorination is used for removal of ammonia nitrogen, the filter is followed by a stabilization tank (not shown in Figure 2) in which the pH is reduced to the 7 - 8 range by adding more carbon dioxide. A control loop using a pH meter is used to control the amount of carbon dioxide introduced into the stabilization tank.

The only instrument now available for measuring the concentration of ammonia nitrogen, nitrate, and phosphorus is the Technicon Auto-analyzer. This instrument has been used successfully for online measurement at about 4 - 5 minute intervals but manual attention is required on all three shifts.

VARIATIONS IN PLANT INFLUENT AND EFFLUENT

A large part of the variability in the product quality in conventional secondary plants can be traced to the diurnal and seasonable variation in influent volume and strength. For example, the diurnal cycle is roughly sinusoidal. The peak to average ratio for flow depends on the size of the plant. The following relationship was found in Orange County, California:[1]

$$\text{Peak Influent Flow, mgd} = 1.84\ (\text{Daily Average Flow, mgd})^{0.92} \qquad (2)$$

The strength of the wastewater tends to vary in a way similar to flow because in periods of low flow particulate tends to settle out in the sewers and in periods of high flow scouring occurs and the settled particulate is carried into the treatment plant.

The variation in strength can also be considered on a statistical basis. Daily average values for BOD in the influent to the Austin, Texas treatment plant were found[2] to average 155 mg/l with a standard deviation of about 50 mg/l. Average dry weather flow in the same plant averaged 23.5 mgd with a standard deviation of only about 2 mgd. Wet weather flow, however, is a continuing problem for treatment plants and the policy in most plants is to bypass when there is danger of overloading the plant. A study of storm overflows made by American Public Works Association[3] for EPA showed that on the average plants bypass 10% of the time due to wet weather.

Townshend[4] studied the effluent quality of plants in Ontario, Canada and found that activated sludge plants averaged about 17 mg/l of BOD in the effluent stream with a standard deviation of about

8 mg/l. Suspended solids concentration in the effluent averaged about 30 mg/l with a standard deviation of about 12 mg/l.

The receiving stream can often adsorb variations in effluent quality but the effect of these variations on downstream tertiary treatment processes might be significant. These variations in effluent quality can be minimized by means of equalization basins, automation, or by increasing the size of the equipment and structures.

These time-dependent effects can be studied by means of dynamic models and some work has been completed in this area. The validation of the models by experimentation is inadequate and much work is needed in this area.

TOTAL COST OF TREATMENT

Conceptually, it is possible to relate the degree of treatment in an activated sludge plant to the total cost of treatment. Some cost factors such as land or administrative cost are known to be independent of the degree of treatment. Other cost factors such as the ones listed below are known to be related to the degree of treatment.

1. Cost of equipment and structures
2. Manpower cost
3. Cost of supplies and utilities
4. Cost of instrumentation and automation

Ideally, the designer and the plant manager should use the proper mix of these resources to achieve the level of treatment demanded at the least total treatment cost.

Figures 3-7 show, in general terms, the cost and effectiveness to be expected from well designed and operated conventional and advanced processes and groups of processes. From these charts we can see that, in general, the cost of removing an increment of pollutant increases as the amount remaining decreases. The cost of treatment also decreases as the size of the plant increases as shown in Figure 8 for conventional activated sludge plant with primary sedimentation. From these charts we can obtain rough values for the cost of removing an additional increment of contaminant.

TOTAL TREATMENT COST VERSUS CONTAMINANT CONCENTRATION REMAINING

FOR

5-DAY BOD REMOVAL

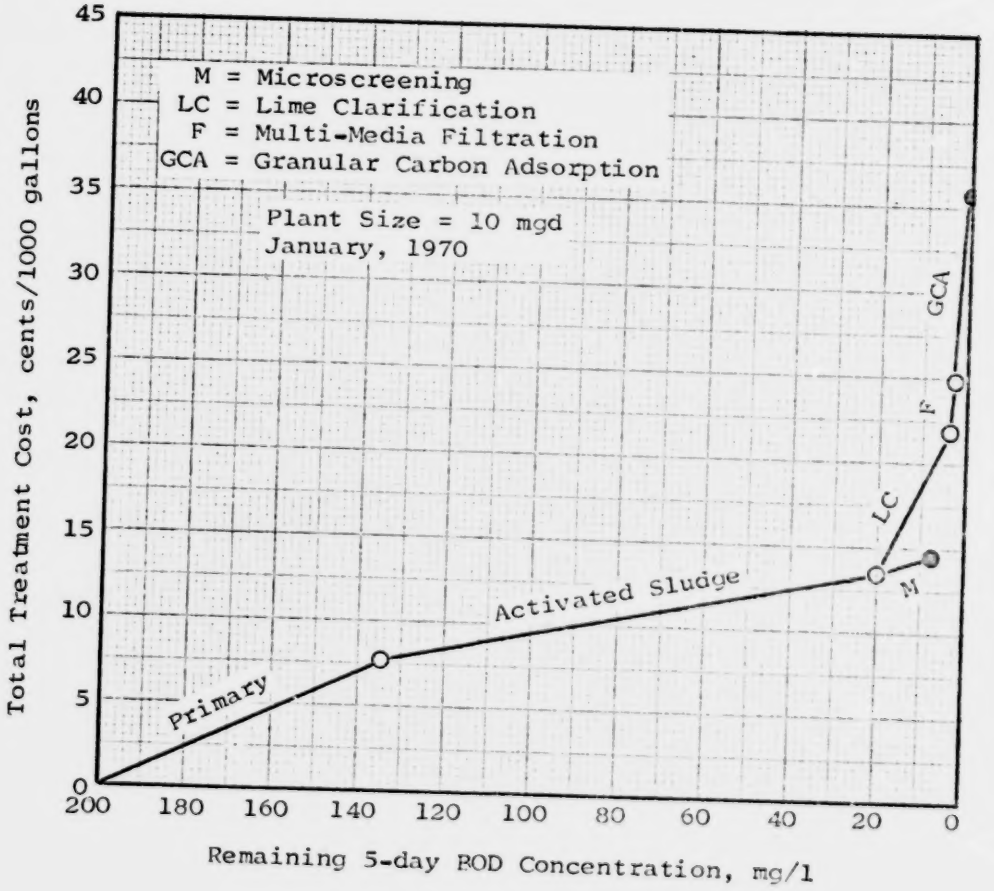


FIGURE 3

TOTAL TREATMENT COST VERSUS CONTAMINANT CONCENTRATION REMAINING
FOR
SUSPENDED SOLIDS

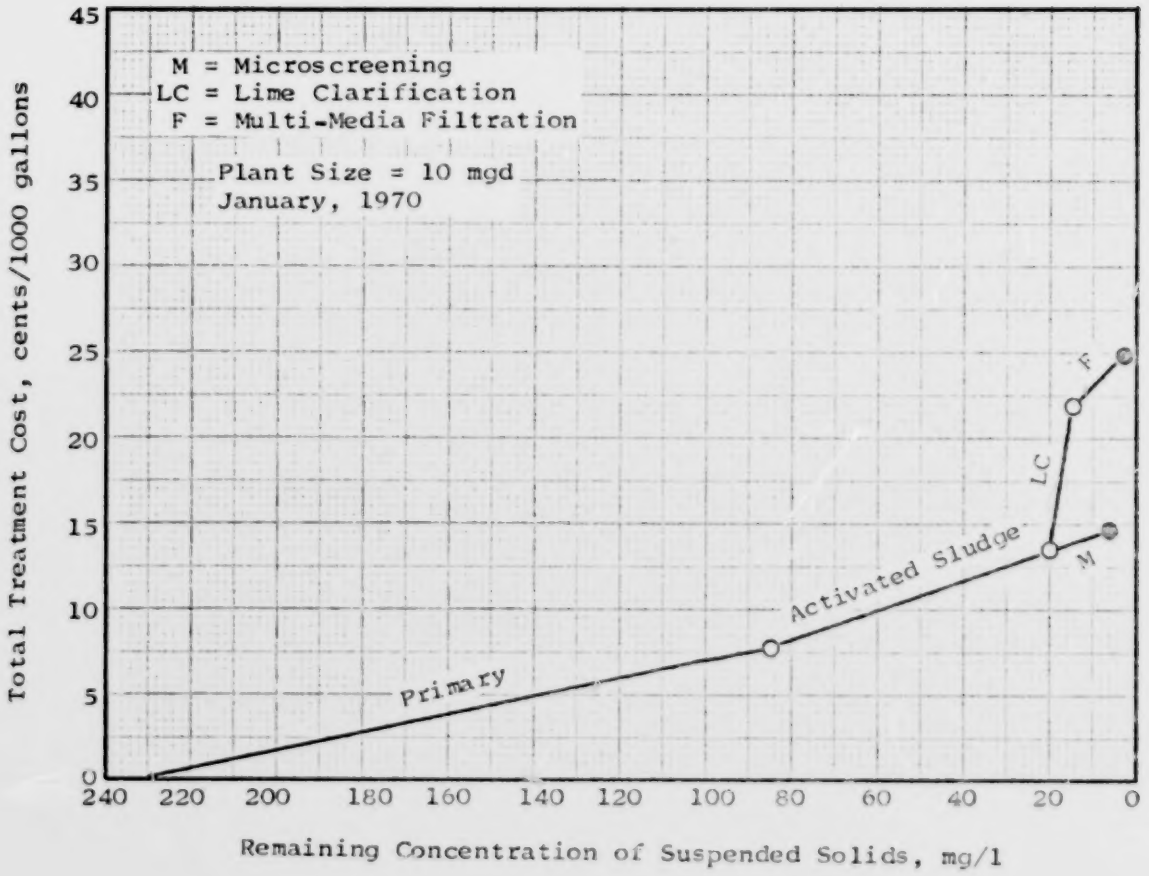


FIGURE 4

TOTAL TREATMENT COST VERSUS CONTAMINANT CONCENTRATION REMAINING

FOR

CHEMICAL OXYGEN DEMAND (COD)

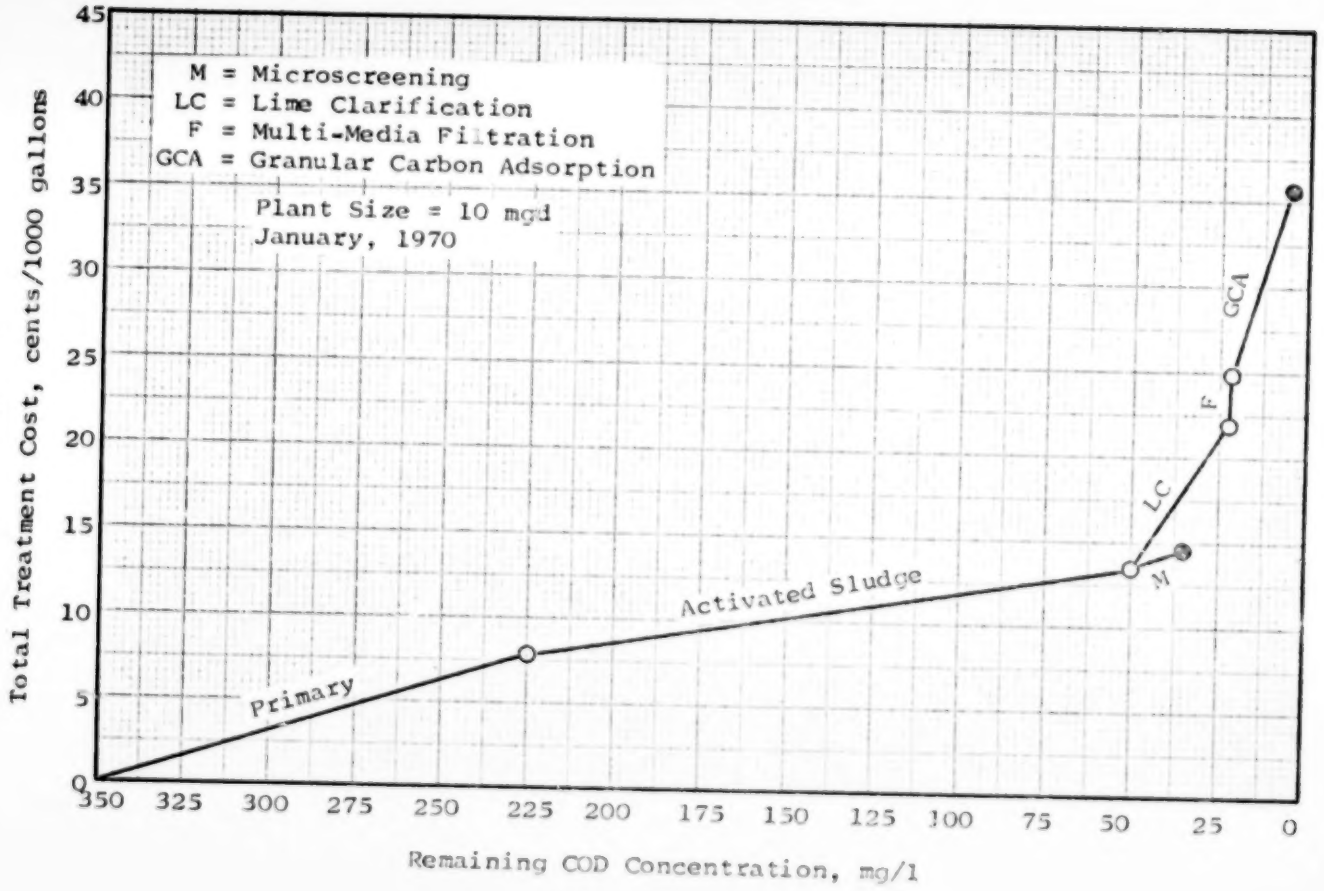


FIGURE 5

TOTAL TREATMENT COST VERSUS CONTAMINANT CONCENTRATION REMAINING

FOR

PHOSPHORUS REMOVAL

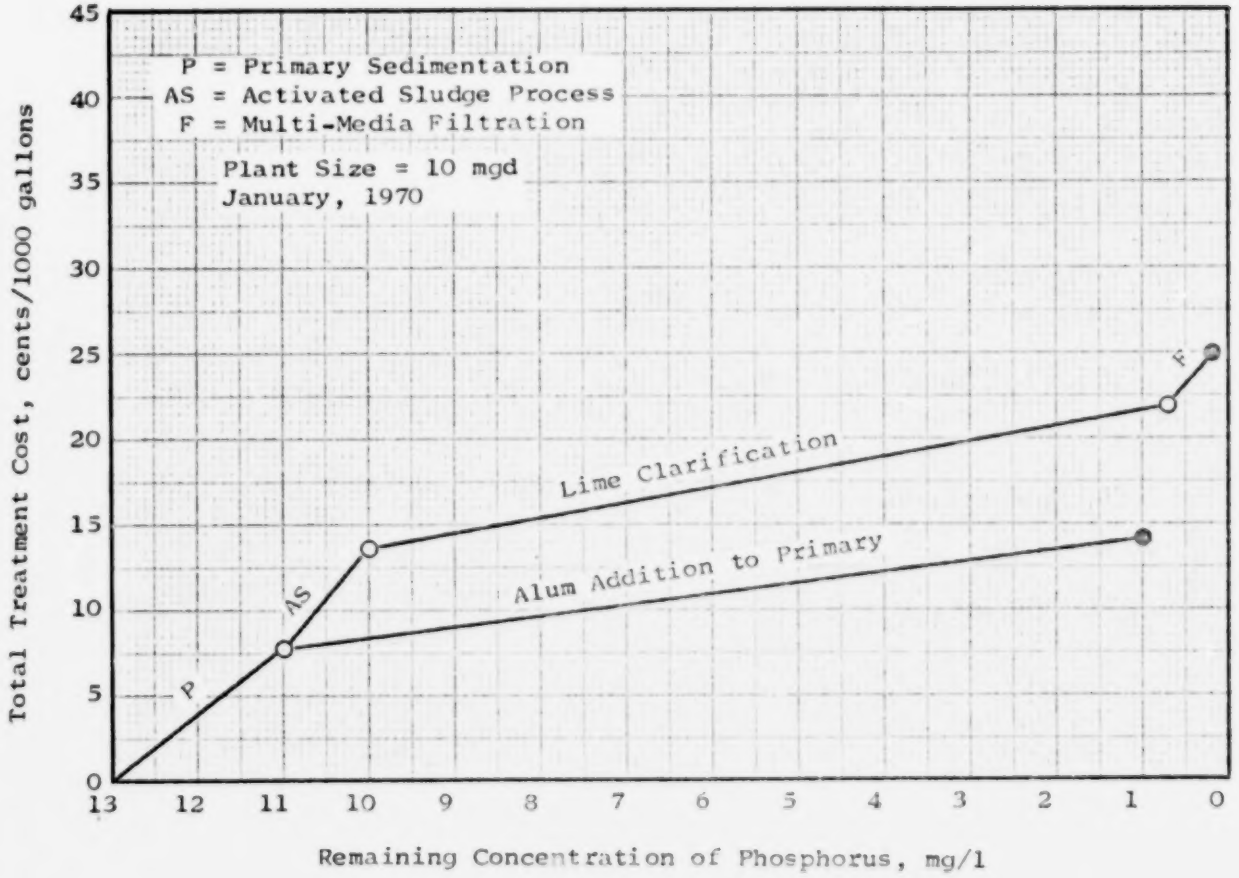


FIGURE 6

TOTAL TREATMENT COST VERSUS CONTAMINANT CONCENTRATION REMAINING

FOR

TOTAL KJELDAHL NITROGEN (TKN)

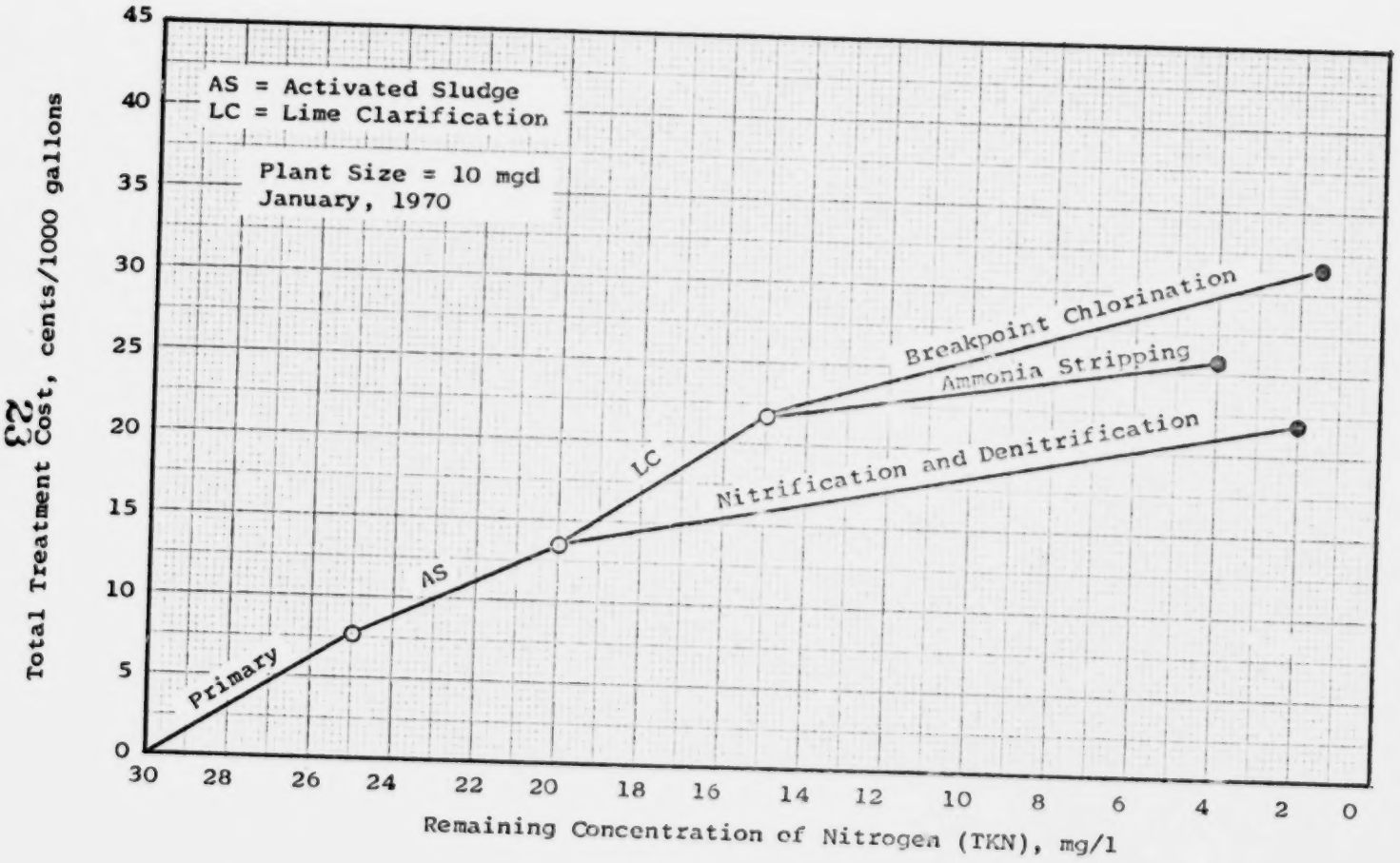
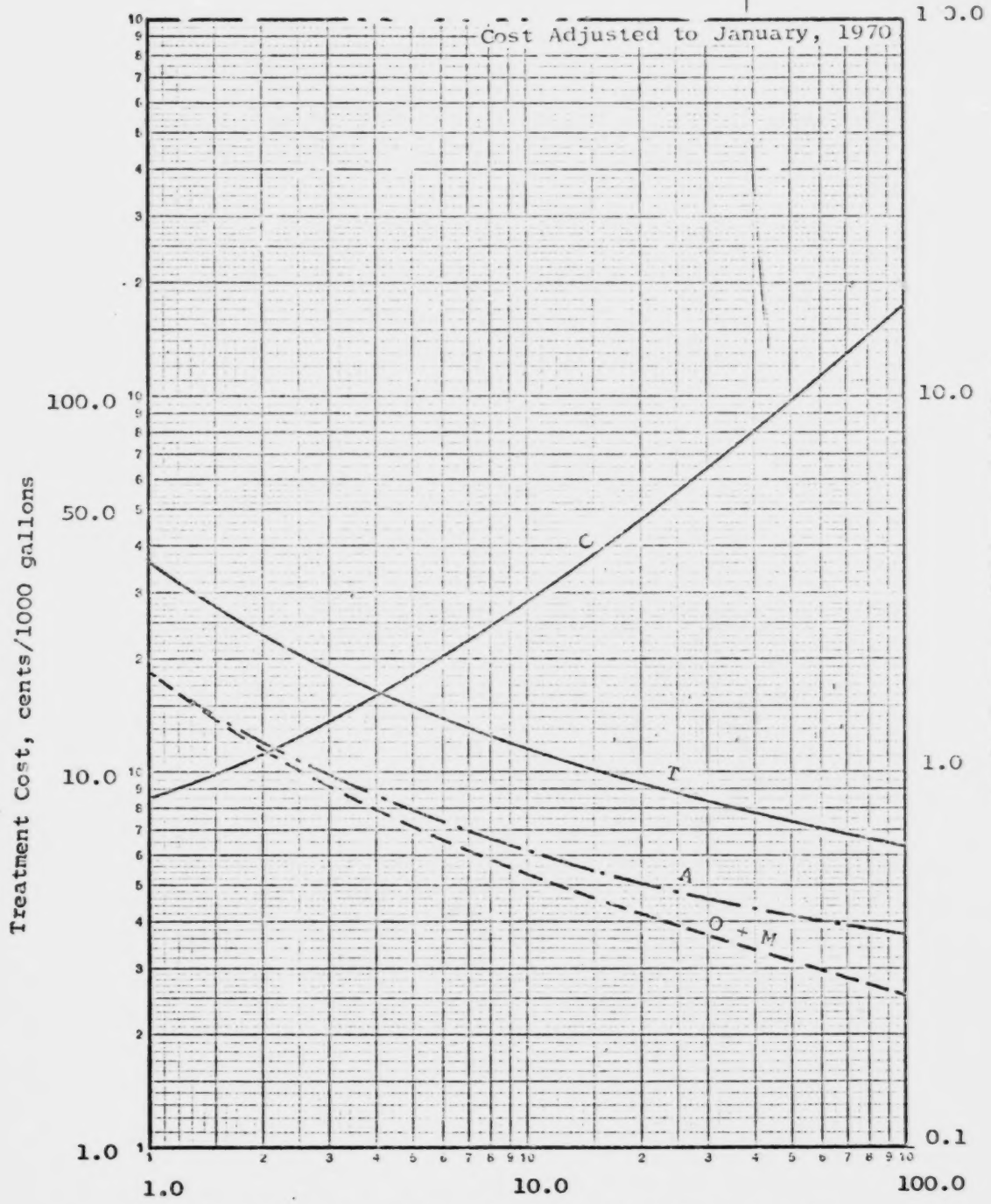


FIGURE 7

ACTIVATED SLUDGE PLANTS

Including: Raw Sewage Pumps, Preliminary Treatment-G+F+S, Primary Sedimentation, Primary Sludge Pumps, Aerators, Diffused Air System, Final Settlers-Multiple, Recirculation Pumps, Sludge Thickener, Anaerobic Digesters, Sludge Drying Beds, Chlorination, Laboratory



C = Capital Cost, millions of dollars
A = Debt Service, cents per 1000 gallons (6% - 25 yr.)
O + M = Operating and Maintenance Cost, cents per 1000 gallons
T = Total Treatment Cost, cents per 1000 gallons

FIGURE 8

The total treatment cost associated with wastewater treatment can be conveniently expressed as cents per pound of pollutant removed from the water. If ΔC is the incremental concentration of the pollutant removed (in milligrams per liter), the cost of removal in cents per pound removed is computed from total treatment cost in cents per 1000 gallons as follows:

$$\text{cents/lb removed} = (\text{cents/1000 gallons})\ (120/\Delta C) \qquad (1)$$

Taking values from Figure 3 for BOD removal the cost of primary sedimentation can be computed as about 13.8 cents/lb. For the activated sludge plant including primary sedimentation the cost is about 9 cents/lb removed. The incremental cost for activated sludge treatment is about 6.5 cents/lb removed. Notice that when lime clarification is added, the incremental cost per pound of BOD removed jumps to about 64 cents/lb of BOD removed. Addition of a microscreen, however, costs roughly the same as activated sludge.

This kind of analysis gives us some basis for deciding whether a given expenditure for improving product quality can be justified. To select one of the factors listed above for effecting improved product quality over all others the incremental cost and effectiveness of each must be known. For example, if we take a nominal value of 10 cents/lb BOD removed, it can be computed that increasing the BOD removal by one mg/l in a 10 mgd plant is equivalent to an expenditure of about $3040/year.

It should be noted that the cost factors listed above can be compared to each other assuming that product quality is fixed. In this way certain kinds of instrumentation and automation can be readily justified. In the following discussion of cost the size of plant considered will be 10 mgd unless noted otherwise.

COST AND AVAILABILITY OF ONLINE INSTRUMENTATION AND CONTROL EQUIPMENT

In discussing the cost of installing various control loops in conventional plants it is often necessary to know how many separate aerators, settling basins or pumps are likely to be installed at any size plant. The maximum surface area for a single settling basin is about 25,000 sq ft. At least two settling basins should be provided to allow for cleaning and repair. The estimated number of separate settlers are shown in Table II. Aerators are normally about 15 feet deep and a maximum of 30 feet wide. A double pass aerator seldom is built greater than 450 feet long. Using these estimates the number of separate aerators for various plant sizes is shown in Table I. Completely mixed anaerobic digesters are sized at about 12,500 cu ft per mgd. The maximum size digester is about 100 feet in diameter with a volume of about 200,000 cu ft. The estimated number of separate digesters as a function of plant size is shown in Table I.

Nuclear adsorption sludge density meters have been installed in many plants to control the density of primary sludge pumped to the anaerobic digester. This kind of meter which is supplied by Industrial Nucleonics, Ohmart, and Nuclear-Chicago has a range of about 1-10% solids. The normal installation uses a timer to start the pumping of sludge at regular intervals. When the sludge density falls to about 3%, the sludge removal pump is shut off. The cost of purchasing the density meter is between $4500 and $5000. Associated recorder costs an additional $700 and installation is about 30% of the equipment cost. Installing one meter, therefore, costs about $7500. The piping can be arranged to use a single sludge density meter to control pumping from all settlers sequentially.

SUMMARY OF TOTAL EXPENDITURES AND SHIPMENTS OF MAJOR ITEMS
1965-1968 (millions of current dollars)

	Water supply				Wastewater disposal			
	1968		1965		1968		1965	
	Mun.	Ind.	Mun.	Ind.	Mun.	Ind.	Mun.	Ind.
Total expenditures	1,800	500	1,500	225	1,700	400	1,300	225
Distribution and collection systems	1,440		1,200		1,130		870	
Treatment plants	360		300		547		415	
	Treatment plant equipment							
Total expenditures	46.3	52.8	50.7	26.3	55.0	34.1	38.7	22.0
Major items								
Aerators	0.7	0.2	0.3	0.1	9.3	8.1	4.6	3.7
Chlorinators	7.8	5.2	7.6	3.1	XX	XX	3.1	1.3
Dewatering, incinerators, wet combuition					16.7	4.4	3.6	1.6
Ion exchange units	6.7	20.1	4.3	1.0	XX	XX	--	--
Meters and controls	16.9	8.8	16.6	8.2	5.0	4.4	4.6	4.0
Pumps	11.3	9.0	11.1	8.6	8.5	6.7	8.2	6.3
Sedimentation	2.9	1.6	1.1	0.7	6.1	4.0	5.7	2.2

XX Combined with water to avoid disclosure of individual company shipments

Source: Kollar, K. L. and William G. Youngwirth, "A Growing Market for Water and Wastewater Treatment Equipment", Water and Sewage Works, September 1970.

TABLE I

ESTIMATED NUMBER OF SEPARATE STRUCTURES

Plant Size	Number of Settling Basins
40 mgd or less	2
60 mgd	3
80 mgd	4
100 mgd	5
120 mgd	6

Plant Size	Number of Aerators
24 mgd or less	2
36 mgd	3
48 mgd	4
60 mgd	5
72 mgd	6
84 mgd	7
96 mgd	8
108 mgd	9
120 mgd	10

Plant Size	Number of Separate Anaerobic Digesters
30 mgd or less	2
45 mgd	3
60 mgd	4
75 mgd	5
90 mgd	6
105 mgd	7
120 mgd	8

TABLE II

Based on the previous estimate of the savings in digester volume associated with increasing the sludge density from 4% to 6% it would appear that the installation of one nuclear radiation density meter can be justified in a 10 mgd plant.

Sludge blanket detectors for the final settler are manufactured by Keene Corp. and can be purchased for $1200. Installation amounts to about 30% of equipment cost. At least one of these meters would be required for each settler. The normal procedure is to have the sensor turn on an additional sludge return pump when the sludge blanket reaches a specified level. The operation of the pump is timed to operate for at least ten minutes but to continue pumping until the sludge blanket drops below the level of the sensor. The obvious purpose of this meter is to prevent the sludge blanket from rising to a point where it begins to escape over the final weirs. A second advantage claimed is that the sludge stored in the final settler is returned to the aerator in time to prevent anaerobiosis with a corresponding deterioration in the settling quality of the sludge. A more sophisticated installation can use two or three sensors at different levels to actuate a set of pumps sequentually. Based on the previous discussion of cost-performance tradeoffs these sludge blanket detectors appear to be well justified for installation in activated sludge plants.

Keene Corp. also manufactures a mixed liquor suspended solids (MLSS) meter which has a range of 500-5000 mg/l with an accuracy of $\pm$ 5%. This sensor operates on the principle of adsorption of back scattered light and sells for about $3500 with an installation cost of about $350. Very little maintenance amounting to monthly

cleaning is required. One industrial treatment plant has been using this sensor for about one year and reports good trouble free performance. In this plant the MLSS is held in the range 4000-4500 mg/l by adjusting the MLSS wasting rate daily. A fundamental problem with this kind of control is the long time constant associated with accumulation of new sludge. This problem was noted at the industrial treatment plant and it was found that about 12 hours was required to increase the MLSS concentration ten percent. A similar result was obtained in computations made with a time-dependent model for the activated sludge process. The performance of the activated sludge process is directly related to the MLSS concentration held in the aerator. In Figure 9 it is shown that at the 20 mg/l BOD level the cost of treatment can be reduced by 0.8 cents/1000 gallons by raising the MLSS from 2000 mg/l to 3800 mg/l. This cost saving would amount to almost $30,000 per year in a 10 mgd plant which clearly would justify the installation of these meters for MLSS. Because of the long time constant manual control of MLSS it appears to be feasible.

The detention time for anaerobic digesters is in the range 15-30 days. Manual measurements of pH, alkalinity, and volatile acids is, therefore, feasible. Gas production and carbon dioxide concentration are normally made automatically.

The Ranarex Department of Permuitit Co. manufactures and supplies an instrument which measures directly the specific gravity of digester gas as compared to atmospheric air. The cost of this instrument is about $1200.

An orifice meter with pneumatic sensor and totalizer for gas measurement of production can be purchased for about $850. Installation is estimated to be an additional 30-40% of equipment cost. A similar instrument using electronics instead of pneumatics would cost about $1700 with installation as an extra charge.

COST OF EQUIPMENT, STRUCTURES AND UTILITIES

The incremental cost of varying the effluent quality by changing the size of the secondary grouping including the aerator, air blowers, sludge return pumps, and final settler is shown in Figure 9. At the 20 mg/l effluent quality point the cost of an incremental change in BOD in the effluent is about 12 cents/lb of BOD removed.

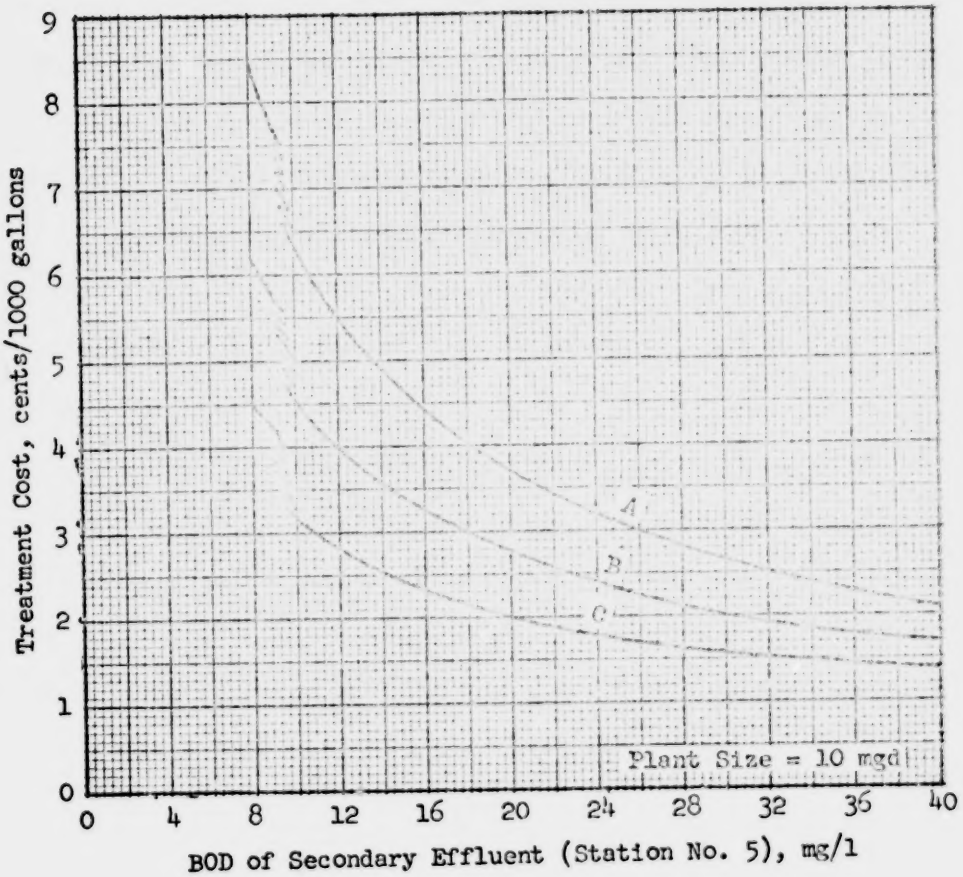
Nuclear radiation meters can be used to control the density of sludge in the primary settler underflow. When the feed sludge density is increased, the size of completely mixed anaerobic digesters can be reduced with a corresponding saving in the cost of constructing and operating the digesters. A computation in which the sludge density was increased from 4% to 6% was made. The cost saving associated with a reduction in digester volume was about 0.3 cents/1000 gallons. The yearly saving for a 10 mgd plant is about $7,300. Using the amortization factor for instrumentation this is equivalent to an installed cost of about $53,700.

Using a time-dependent model for the activated sludge process[5] the oxygen requirements in a system where the flow and BOD concentration vary sinusoidally has been computed. The peak to average ratio for flow was 1.35. For BOD concentration the peak to average ratio was 1.67. The oxygen needed to meet requirements at the peak conditions was about 1.6 times the average consumption. From this we might conclude that if, by means of a control loop involving dissolved oxygen meters and throttling control on the air blowers, the air supply can be matched to the air demand; the savings in electrical power would equal about 40% of the air required

TOTAL TREATMENT COST FOR SECONDARY GROUPING

versus

BOD OF SECONDARY EFFLUENT (Station No. 5)



CONDITIONS: 1. FRPS equals 0.5
2. Influent BOD (Station No. 2) equals 130 mg/1

LABELS: A - Aerator MLSS equals 1200 mg/1
B - Aerator MLSS equals 2000 mg/1
C - Aerator MLSS equals 3800 mg/1

NOTE: Broken Line Indicates That Nitrification Has Occurred

SOURCE: Smith, Robert, "Preliminary Design and Simulation of Conventional Wastewater Renovation Systems Using the Digital Computer", USDI, FWPCA, Water Pollution Control Research Series No. WP-20-9, March 1968.

FIGURE 9

at the peak condition. The calculation showed that with nitrification the oxygen consumption at the peak was about 1.4 scf per gallon treated. The cost saving in terms of dollars per year for a 10 mgd plant is about $5,600/year. This is equivalent to installing about $41,000 worth of control equipment.

The final settler is known to be a key process in controlling the amount of suspended solids which escape into the final effluent. A cost calculation[6] for a 10 mgd plant showed that reducing the overflow rate for the final settlers from 1000 gpd/sq ft to 800 gpd/sq ft resulted in an overall cost increase of 0.15 cents/1000 gallons. This is equivalent to $5500 per year. If the BOD in the effluent can be reduced by 2 parts per million by means of this decision, it would appear that it is justified.

Sludge return pumps are often undersize and cannot return sufficient activated sludge from the final settler resulting in sludge escaping over the final weirs. A cost computation[6] was made in which the fraction of the feed stream returned was increased from 75% to 150%. The increase in cost was about 0.093 cents/1000 gallons. This is equivalent to about $3900 per year and should result in a reduction in BOD of about 1.3 mg/l.

These examples are meant only to show the rationale for deciding when an increase in the size of equipment and structures is justified. Notice that information by which the improvement in product quality can be related to the associated cost is almost wholly lacking. The idea of relating the cost of manpower, or new equipment and structures.

or automatic control equipment to the corresponding gain in effluent quality is clear enough. There is a great need for experimental measurement programs in which the plant performance is measured before and after the installation of a particular control loop.

These measurements will be difficult to make because the influent stream to the plant varies in volume, strength, and composition on a diurnal basis and from day to day and from season to season.

MANPOWER

The average wages of nonsupervisory workers in the water, steam, and sanitary systems area was $3.68 in February, 1971.[1] Adding 15% to this for payroll extras and supervision gives an average salary of $8,803 per year for one additional man. Addition of one man should, therefore, effect an improvement in product quality of about 3 mg/l BOD.

Estimates of manpower to staff activated sludge plants are shown in Figure 10. The estimates given by the State Sanitary Engineers[7] are minimum requirements. The estimates made by Black and Veatch[8] represent their estimate of proper staffing. The line contributed by Michel[9] reflects the actual staffing of plants as of 1969.

Instrumentation and control equipment normally has a useful life of about 10 years. If we assume an interest rate of 6%, the amortization factor for instrumentation and control equipment is 0.13587. Reducing the concentration of BOD in the effluent by one mg/l can, therefore, justify the expenditure of $22,374 for a ten mgd plant. On an equivalent cost basis one additional man is equivalent to $64,800 invested in instrumentation and control equipment.

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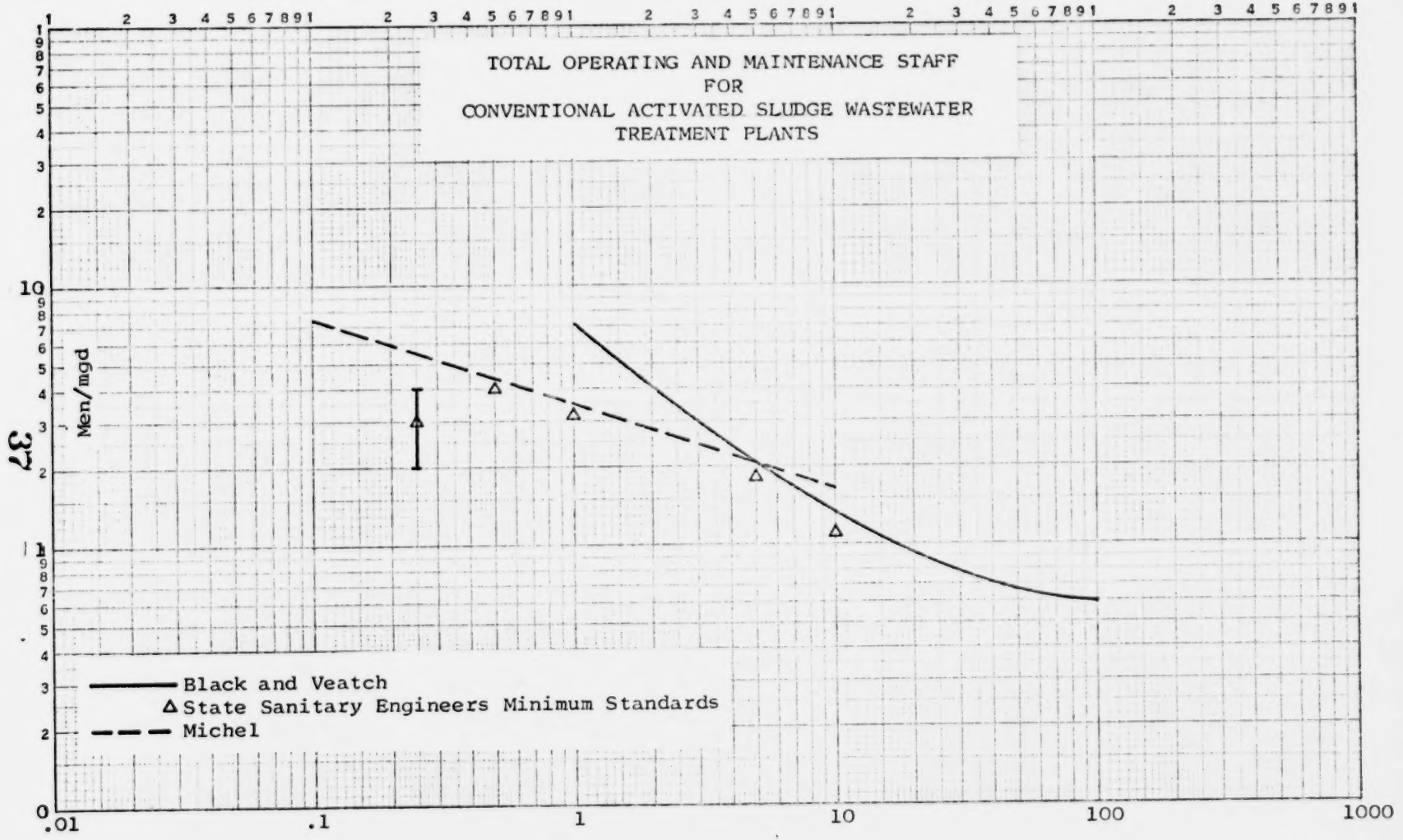

FIGURE 10

CURRENT EXPENDITURES FOR METERS AND CONTROLS

The U. S. Department of Commerce has recently published[10] information on the expenditures for meters and controls in municipal and industrial wastewater treatment. This data is shown in Table I. Excluding package treatment plants and package pumping stations the cost of purchased equipment is shown in the Department of Commerce publication to represent about 10% of the total construction cost of the wastewater treatment plant. A similar study published by the U. S. Department of Labor in 1963 estimated the cost of equipment in sewage treatment plants as 13.4% of the total construction cost. According to the U.S.D.C. study the expenditure for meters and controls in wastewater treatment plants decreased from 12% to 9% for municipal plants and from 18% to 13% for industrial plants between 1965 and 1968. The expenditure for meters and controls was higher for industrial plants in both years.

Another conclusion which can be drawn from the U.S.D.C. data is that expenditure for meters and controls in water treatment plants exceeds that for wastewater treatment plants. For example, in 1968 meters and controls represented 36.5% of equipment expenditure for municipal plants and 16.6% for industrial plants. In 1965 the percentage expenditure for water treatment plants was about 32% of equipment for both municipal and industrial plants.

If we take the cost of equipment purchase as 10-15% of the total construction cost and the cost of meters and controls as 10% of the equipment cost, the cost of meters and controls for wastewater treatment plants is about 1-1.5% of the construction cost. For water treatment plants the cost of equipment is about 15% of the

construction cost. Since meters and controls represent about 34% of all equipment, the cost of meters and controls amount to about 5% of the plant construction cost. This significant difference in expenditure for meters and controls between water treatment plants and wastewater treatment plants reflects the fact that water treatment plants must keep effluent quality at or above a fixed standard to protect the customer's health and to minimize customer complaints. If effluent standards could be enforced for wastewater treatment plants, the emphasis on meters and controls would probably approach that which now exists for water treatment plants.

The capital cost of a conventional activated sludge plant to treat ten million gallons per day is about $2.85 million. According to the U.S.D.C. data the expenditure for meters and controls now amounts to about $30,000 to $40,000. If the expenditure for meters and controls were made 5% corresponding to that now spent in water treatment plants, the expenditure for meters and controls would be about $143,000.

Instruments and automatic control in the chemical industry average 5 - 7½% of the plant cost. Another good rule of thumb is to allow $3000 - $4000 per equipment module for instruments and controls. The total cost of chemical plants is about 3 - 4½ times the cost of installed equipment. The cost of instruments and controls are therefore, about 20 - 30% of installed equipment. This is approximately equivalent to the expenditure for meters and controls in water treatment.

REFERENCES

1. Boyle Engineering and Lowry and Associates, "Master Plan Trunk Sewer Facilities" for County Sanitation District No. 3 of Orange County, California, June 1968.

2. FWPCA Grant No. WPRD 178-01-68, "Design Guides for Biological Wastewater Treatment Processes", by the University of Texas at Austin, March 1971.

3. Federal Water Pollution Control Administration, U.S. Department of the Interior, Problems of Combined Sewer Facilities and Overflows 1967, Water Pollution Control Series, WP-20-11, 1967.

4. Townshend, A. R., "Statistical Analysis of the Effluent Quality of Biological Sewage Treatment Processes", Design Approvals Branch, Ontario Water Resources Commission, Toronto, Canada.

5. Smith, Robert and Richard G. Eilers, "Simulation of the Time-Dependent Performance of the Activated Sludge Process Using the Digital Computer", FWQA Publication, October 1970.

6. Eilers, Richard G. and Robert Smith, "Wastewater Treatment Plant Cost Estimating Program", WQO Publication, April 1971.

7. "Recommendations for Minimum Personnel, Laboratory Control, and Records for Municipal Waste Treatment Works". Adopted by the Conference of State Sanitary Engineers at their 38th Annual Meeting, June 1963.

8. Preliminary Data from EPA Contract No. 14-12-462, "Studies to Establish Construction and Operating Costs for Unit Processes of Conventional Waste Treatment Plants", with Black and Veatch Consulting Engineers.

9. Michel, Robert L. and Walter W. Johnson, "Cost and Man-Hours For Operation and Maintenance of Municipal Wastewater Treatment Plants 1957 to 1970", Preliminary FWQA Publication, October 1970.

10. Kollar, K. L. and William G. Youngwirth, "A Growing Market for Water and Wastewater Treatment Equipment", Water and Sewage Works, September 1970.

APPENDIX I

PROPOSED AUTOMATIC CONTROL SCHEMES
FOR CONVENTIONAL WASTEWATER TREATMENT
PROCESSES

PROCESS NAME	PROCESS VARIABLE TO BE CONTROLLED	EXTERNAL LOAD	INTERNAL LOAD	PROCESS VARIABLE AVAILABLE FOR COMPENSATION
Bar Screens	differential pressure across bar screen	varying load of debris in raw sewage		frequency of cleaning cycle
Grit Chambers	liquid velocity to be kept below design value. Measure volume flow. Compute liquid velocity.	varying hydraulic load on plant		store liquid or divert to other grit chambers
Prechlorination	Oxidation-Reduction Potential of chlorinated wastewater	varying degrees of anaerobiosis		chlorine dose is varied to maintain a specific ORP
Primary Settler	concentration of sludge of underflow as measured by nuclear radiation density meter	varying settleable solids load	underflow concentration varys with time and amount of sludge stored	sludge pumping cycle, pumping begins when concentration exceeds set point and stops when concentration falls below set point
Primary Settler	simple alarm		failure of flights due to year or excessive loads	shut off electrical power to flights, sound alarm
*Primary Settler	suspended solids of effluent stream	varying hydraulic and suspended solids load		addition of chemicals such as alum or iron

PROCESS NAME	PROCESS VARIABLE TO BE CONTROLLED	EXTERNAL LOAD	INTERNAL LOAD	PROCESS VARIABLE AVAILABLE FOR COMPENSATION
Trickling Filter	recycle volume flow proportional to influent but not to be less than some set point	varying primary effluent volume flow		recycle pumping rate
Activated Sludge Process	influent flow rate	varying volume flow into plant		hold influent flow constant by means of equalization tank with pumping
Activated Sludge Process	Dissolved oxygen concentration in aerator	varying hydraulic and organic loads	varying amount and activity of active solids held in aerator	amount of diffused air supplied or power to mechanical aerators
Activated Sludge Process	ORP of aerator effluent	varying hydraulic and organic loads		vary diffused or mechanical air supply
Activated Sludge Process	hold recycle stream at some fraction of influent stream	varying hydraulic load on process		recycle pumping rate
Activated Sludge Process	sludge blanket level in final settler		varying settling and compaction characteristics of activated sludge	recycle pumping rate
*Activated Sludge Process	Food/microorganism ratio in aerator	varying hydraulic and organic loads		control return of activated sludge from storage tank

PROCESS NAME	PROCESS VARIABLE TO BE CONTROLLED	EXTERNAL LOAD	INTERNAL LOAD	PROCESS VARIABLE AVAILABLE FOR COMPENSATION
*Activated Sludge Process	Activated sludge concentration in aerator	varying hydraulic and organic loads		control waste activated sludge stream or return sludge stream from storage tank
Digesters	Charging rate	sludge density and toxicity	biological condition of digester as indicated by volatile acids, CO_2 fraction, gas production rate	frequency and amount of charge using magnetic flow meter and nuclear density gauge
Digesters	sludge temperature	environmental conditions		heat supplied
All Rotating Machinery	bearing temperature	wear or excessive loads		sound alarm or shut off power

*Not Yet Technically Feasible